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Remote sensing of crop coefficients for improving the irrigation scheduling of corn

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Abstract

Improved irrigation water management requires accurate scheduling of irrigations which in turn requires an accurate calculation of daily crop evapotranspiration (E_t). Previous work by Neale et al. (1989) and Bausch (1993) have indicated that the reflectance-based crop coefficient (K_{cr}) for corn responded to crop growth anomalies and should improve irrigation scheduling. Thus, the purpose of this study was to develop a new procedure for using the K_{cr} in irrigation scheduling and present results of simulations comparing different basal crop coefficient (K_{cb}) curves for corn to evaluate their effects on estimated crop E_t. Irrigation scheduling simulations were performed using SCHED, the USDA-ARS Irrigation Scheduling Program, and three K_{cb} curves (the one in SCHED, Wright's (1982) tabular data, and the K_{cr}-based K_{cb}). Simulated crop water use using the K_{cb} curve in SCHED was considerably greater during vegetative growth (60 to 100 mm) than simulated crop water use using Wright's K_{cb} or the K_{cr} derived K_{cb} curves for three growing seasons. Crop water use between the K_{cr}-based K_{cb} and Wright's K_{cb} were different by approximately 20 mm each growing season. Crop water use was less in 1990 and 1992 for the K_{cr} derived curve and greater for 1991; crop development was directly responsible for the differences. Although the differences between the Wright and K_{cr} basal crop curves were minimal, irrigations with the K_{cr}-based K_{cb} were more appropriately timed. Irrigations that are correctly timed minimize overirrigation as well as underirrigation.

Keywords: Remote sensing; Canopy reflectance; Evapotranspiration; Crop coefficients; Irrigation scheduling; Simulation

1. Introduction

Irrigation scheduling programs such as the one initiated by Jensen (1969) require an estimate of daily crop evapotranspiration (E_t). Crop E_t was estimated from calculated reference E_t and crop coefficients. Further developments to this computer model by Jensen

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et al. (1970, 1971), Kincaid and Heermann (1974), Harrington and Heermann (1981) and Buchleiter et al. (1988) maintained the two-step procedure for estimating daily crop E_t because it provides a practical method for calculating actual crop evapotranspiration throughout a growing season.

Introduction of the basal crop coefficient (K_{cb}) by Wright (1982) greatly improved the transferability of crop coefficients to other climatic regions. Unfortunately, the driver for this crop coefficient is still percent of time from planting to effective cover and elapsed days after effective cover. Utilization of this driver requires a guess as to when effective cover will occur. Effective cover for E_t of agricultural crops has been considered to occur around a leaf area index (LAI) of 3 and/or 75% ground cover (Stegman et al., 1980). Hinkle et al. (1984) reported LAI values ranging from 2.2 to 3.2 at effective cover for several different varieties of corn with different maturation periods. Consequently, a unique LAI may not exist that represents effective cover. Plant development (size, shape, orientation and distribution of leaves, etc.) and root system development greatly influence the occurrence of effective cover.

Hinkle et al. (1984), Sammis et al. (1985), Stegman (1988) and Amos et al. (1989) utilized heat units (growing degree days or fraction growing degree days) as the driver for crop coefficient curves. This driver represents the crop coefficient curve as a continuous function for the growing season thus making the equations more practical for field use. Hinkle et al. (1984) and Amos et al. (1989) showed that fraction of growing degree days normalized the crop coefficient curves for cultivars that have different growing season lengths.

Bausch and Neale (1987) and Neale et al. (1989) have shown the usefulness of remotely sensed data to represent a reflectance-based crop coefficient (K_{cr}) for corn. Neale et al. (1989) reported that effective cover for corn occurred when the normalized difference vegetation index (NDVI) reached its maximum value. Advantages of this crop coefficient over traditional crop coefficients are (1) they are independent of the time base variable and (2) they are sensitive to periods of slow and fast growth induced by weather conditions. Consequently, the K_{cr} represents a real-time crop coefficient that responds to actual crop conditions in the field.

Bausch and Neale (1989) and Bausch (1989) demonstrated use of the K_{cr} in irrigation scheduling. An algorithm was developed to shift the basal crop coefficient curve for corn with respect to the time dependent axis to make the K_{cb} represent actual crop growth in the field. Basically, the algorithm was a trial and error solution operating within known constraints developed from several years of data. Updating the K_{cb} curve with K_{cr} data prior to effective cover forced the assumed effective cover date to converge on the actual effective cover date. Simulated irrigation events were shown to occur one to three days earlier prior to effective cover using the K_{cr} as opposed to the simulations with the traditional K_{cb}. After effective cover, simulated irrigation dates using the K_{cr} lagged one or two days behind simulated irrigations when using the traditional K_{cb}.

Recently, Bausch (1993) improved the reflectance-based crop coefficient for corn by using the soil adjusted vegetation index (SAVI) (Huete, 1988) to represent the K_{cr}. Consequently, soil background effects were minimized which eliminates additional calibration for different soils.

The objective of this article was to develop a new procedure for using the improved K_{cr}

in irrigation scheduling and present results of simulations using different basal crop coefficient curves for corn to evaluate their effects on estimated crop E_t. Three representations of the K_{cb} curve for corn were selected; these were (1) the K_{cb} curve as defined in SCHED, the USDA-ARS Irrigation Scheduling Program (Buchleiter et al., 1988), (2) Wright's (1982) tabular data and (3) the K_{cb} curve defined using K_{cr} data.

2. Methods

Experimental data used in the simulations were collected during the 1990, 1991 and 1992 growing seasons at the Agricultural Engineering Research Center (40.59°N lat., 105.14°W long.), Colorado State University, Ft. Collins, CO. Corn (*Zea mays* L.) was planted in two field plots approximately 45 × 45 m. Row direction was north/south; row spacing was 0.76 m. Table 1 lists cultivar used, key phenological events and plant population for each growing season. A two-tower center pivot sprinkler was used to irrigate the plot area. The irrigation scheme used in 1990 and 1991 consisted of applying approximately 20 mm of water every 3 to 4 days; allowances were made for rainfall. Irrigations were scheduled in 1992 with SCHED when 50% of the plant available water was depleted within the crop root zone; application depth was 1.2 times calculated crop E_t. The crop was never exposed to water stress during any growing season.

Soil in the plot area was classified as a fine-loamy, mixed, mesic Aridic Haplustoll. Water holding capacity was 0.12 mm/mm. Maximum rooting depth was limited to 0.68 m due to soil profile characteristics.

Leaf area from the first to fourth leaf growth stage [V1-V4 (Ritchie et al., 1986)] was determined on 10 average-sized plants harvested from the plots at each growth stage. Leaf

Table 1
Corn cultivar, key phenological events, and plant population for the 1990, 1991, and 1992 growing seasons

	Growing season		
	1990	1991	1992
Cultivar	Pioneer 3732	Pioneer 3732	Pioneer 3645
Phenological event			
Planting	23 April (113)*	2 May (122)	29 April (120)
Emergence	13 May (134)	16 May (136)	10 May (131)
6th Leaf	14 June (165)	17 June (168)	16 June (168)
Tassel	27 July (208)	29 July (210)	29 July (211)
Dent	7 Sept. (250)	13 Sept. (256)	22 Sept. (266)
Blacklayer	1 Oct. (274)	3 Oct. (276)	11 Oct. (285)
Harvest	4 Oct. (277)	8 Oct. (281)	20 Oct. (294)
Plant population (plants/m^2)	7.3	7.0	7.2

*DOY in parenthesis following calendar day.

area was measured in the laboratory with a Li-Cor LI-3100 area meter. Starting with the V5 growth stage, leaf area was measured in the field with a portable Li-Cor LI-3000A area meter at least twice per week on 10 randomly selected plants. Leaf area index (LAI) was calculated based on knowledge of the plant population.

Corn canopy radiance and incoming irradiance were measured with a mobile data acquisition system (Bausch et al., 1990). This system consisted of an instrument platform with two Exotech 100BX four-channel radiometers mounted on a boom; radiometer height was 10 m above ground. The down-looking radiometer measured canopy radiance through 15° circular field of view (FOV) optics. It was pointed perpendicular to the surface of the target, that is, a nadir view angle. The other radiometer looked upward to measure irradiance at the same instant in time; it was fitted with 2π steradian FOV optics. Radiant energy was measured in the blue (0.45–0.52 μm), green (0.52–0.60 μm), red (0.63–0.69 μm) and near-infrared (0.76–0.90 μm) wavebands. These wavebands are similar to Landsat Thematic Mapper Bands TM1, TM2, TM3 and TM4, respectively. An Omnidata Polycorder (model 516B) sampled voltages from the radiometers and logged the data.

Canopy radiance was measured at least three times per week. On any particular measurement date, data acquisition bracketed solar noon. Each measurement sequence started and ended with the radiometer optics covered to measure voltage noise on each of the four channels.

Bidirectional reflectance of the target was calculated for each of the four wavebands using a procedure similar to that presented by Duggin (1980), as described by Neale (1987). These data were used to calculate the soil adjusted vegetation index (SAVI) as developed by Huete (1988). SAVI is defined by

$$\mathrm{SAVI} = \frac{\mathrm{TM4} - \mathrm{TM3}}{\mathrm{TM4} + \mathrm{TM3} + L} \times (1 + L) \tag{1}$$

where L is an adjustment factor. Huete (1988) and Bausch (1993) showed that soil background influences on canopy reflectance was adequately minimized for canopy cover ranging from sparse to dense with $L = 0.5$. The reflectance-based crop coefficient (K_{cr}) for corn (Bausch, 1993) was calculated using

$$K_{cr} = 1.416 \times \mathrm{SAVI} + 0.017. \tag{2}$$

Irrigation scheduling simulations were performed using SCHED (Buchleiter et al., 1988) which was primarily developed for center pivot irrigation management. This computer model calculates daily alfalfa reference evapotranspiration (E_{tr}) based on the modified Penman equation using empirical coefficients developed by Kincaid and Heermann (1974) at Mitchell, NE. Crop root development was assumed to vary linearly from 0.15 m at emergence to the maximum depth of 0.68 m at effective cover and remained at that depth thereafter. The management allowed depletion of available soil water within the crop root zone was set at 50%. Therefore, whenever the management allowed depletion exceeded 50% or 20 mm, an irrigation equal to the calculated depletion occurred. Climatic data for the calculation of E_{tr} was measured by an automated weather station adjacent to the corn

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plots. Rainfall was ignored in the simulations and each simulation began with a full soil water profile. Irrigation for the season was terminated when the R5 (dent) growth stage occurred.

3. Results and discussion

3.1. Algorithm development

Since K_{cr} data were not available on a daily basis, a procedure was required to estimate a daily basal crop coefficient based on available K_{cr} data. Due to the success of Hinkle et al. (1984) and Amos et al. (1989) with fraction growing degree days as a driver for their crop coefficient curves, this driver was selected as the driver for the K_{cb} curve derived from K_{cr} data. The 10–30°C temperature threshold growing degree day method was used with growing degree days accumulated from planting. This method was selected because the hybrid corn seed companies use it to provide growing degree days required from planting to blacklayer formation (growth stage R6) for the various cultivars. Fraction growing degree days from planting were calculated by dividing accumulated growing degree days by the total season growing degree days published by the corn seed company for the particular cultivar.

Fig. 1 represents the 1990 growing season basal crop coefficient curve for corn generated from K_{cr} data. The K_{cb} curve is generated using linear segments as K_{cr} data is made available from measured canopy reflectance. It starts with a slope of zero and an intercept of 0.15 at planting (Wright, 1982). Thus, daily estimates of the K_{cb} are calculated from

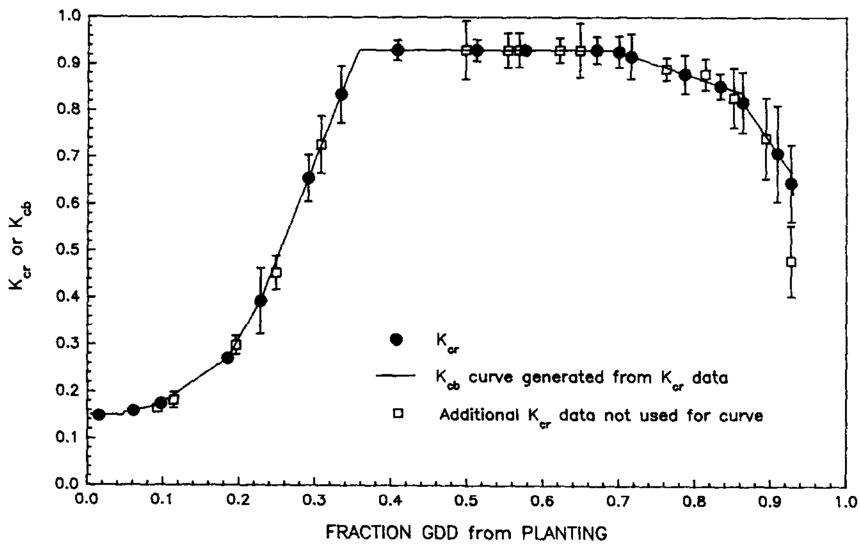

Fig. 1. Example of the basal crop coefficient (K_{cb}) curve for corn generated using the reflectance-based crop coefficient (K_{cr}) calculated from measured canopy reflectance in 1990.

$K_{cb} = a + b(\text{fractGDD})$; a is the intercept, b is the slope and fractGDD is the fraction of accumulated growing degree days from planting. Beginning with the second and each successive K_{cr} data point, the K_{cb} calculated from the linear equation on the day of K_{cr} data is compared to the 95% confidence limits on the mean K_{cr}; if it is within the confidence limits on K_{cr}, the current slope and intercept are retained. If the K_{cb} is outside the confidence limits on K_{cr}, then a new slope and intercept are calculated using the two most recent available K_{cr} data points.

All K_{cr} data shown in Fig. 1 were acquired under ideal or near-ideal sky conditions; that is, data were omitted when clouds obscured the sun. K_{cr} data designated by open squares were included to show that other data not selected for generating the basal crop coefficient curve also fell on the K_{cb} curve. Weekly acquisition of canopy reflectance data would suffice to develop the basal crop coefficient curve. However, one should be cognizant of the sky conditions when canopy reflectance is acquired. Clouds partly or fully blocking the sun increase the SAVI; these data could be used provided some reasonable technique was available to decrease the SAVI in relation to sky cloudiness. Bausch (1993) demonstrated that the SAVI could be used to calculate the K_{cr} for these conditions from knowledge of sky cloudiness effects on the SAVI and observation of sky conditions at the time of data acquisition.

3.2. Crop coefficient curve impact on crop water use

Irrigation scheduling simulations using the K_{cb} curve in SCHED as well as Wright's (1982) K_{cb} data required knowledge of the effective cover date. Therefore, the best guess at this date was obtained from a curve fit through measured LAI data assuming that effective

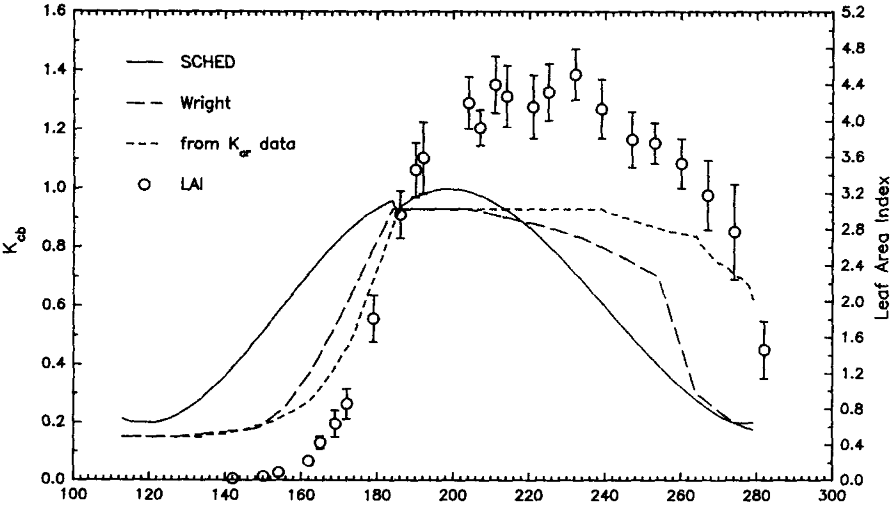

Fig. 2. Basal crop coefficient (K_{cb}) curves used in the 1990 growing season irrigation scheduling simulations.

Table 2
Simulated irrigation dates and crop water use for the 1990 growing season

Basal crop coefficient curve					
SCHED		Wright		K_{cr}	
Irrigation date	Crop use (mm)	Irrigation date	Crop use (mm)	Irrigation date	Crop use (mm)
122	9.0	127	9.7	127	9.7
127	9.1	145	16.9	145	16.5
134	9.9	158	20.5	159	21.0
140	13.5	164	22.4	166	20.4
145	16.6	169	20.4	171	20.3
153	21.8	174	22.5	176	21.5
158	22.7	178	24.3	180	24.3
162	23.2	181	20.9	183	21.4
166	22.4	184	21.4	188	24.8
169	20.9	189	21.0	194	23.6
173	21.8	194	22.2	198	23.0
176	20.5	198	23.0	203	20.3
179	21.2	203	20.3	208	24.8
182	21.0	208	24.7	213	20.8
186	24.4	213	20.3	218	21.4
192	23.6	218	20.9	222	22.4
196	23.0	222	22.2	227	21.2
200	25.8	227	20.6	232	20.9
206	23.6	233	23.7	237	25.2
211	24.1	238	25.0	241	25.0
216	20.9	242	23.4	246	22.7
220	20.7	248	23.6		
225	21.6				
231	22.0				
237	22.7				
242	23.8				
250	21.6				

Table 3
Simulated crop water use and number of irrigations for 1990 from planting to effective cover and for the growing season

	Basal crop coefficient curve					
	SCHED		Wright		K_{cr}	
Time period	Crop use (mm)	Irrigations	Crop use (mm)	Irrigations	Crop use (mm)	Irrigations
Effective cover	254	14	179	9	155	8
Dent	551	27	470	22	451	21

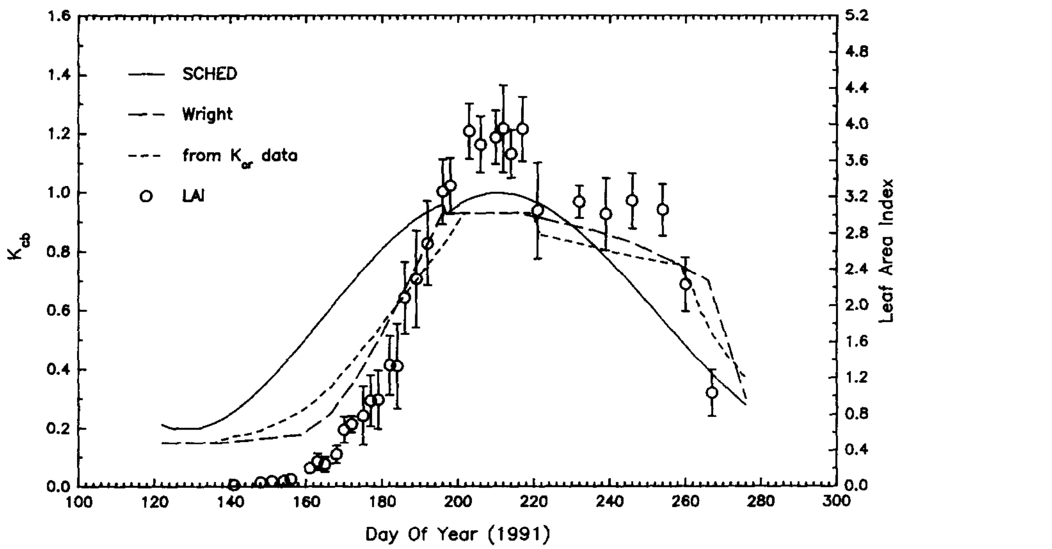

Fig. 3. Basal crop coefficient (K_{cb}) curves used in the 1991 growing season irrigation scheduling simulations.

cover occurred when LAI = 3. To compare the K_{cb} curve derived from K_{cr} data with the above K_{cb} curves, Day of Year (DOY) was selected as a common temporal scale.

Fig. 2 represents the 1990 growing season K_{cb} curves used in the simulations. Measured LAI data were included to show comparisons of the crop coefficient curves with leaf area development. Effective cover from LAI data was determined to occur on DOY 184; the K_{cb} curve from K_{cr} data peaked on DOY 186. Simulated irrigation dates (listed as DOY) and crop water use at that time for each basal crop coefficient curve are given in Table 2 for the 1990 growing season. Irrigation dates indicating crop water use less than 20 mm occurred due to a shallow root zone at the time and the fact that 50% of the plant available water had been depleted. Recall that rainfall was ignored.

Number of irrigations and crop water use were considerably different for the three crop coefficient curves. The crop curve in SCHED required more irrigations and indicated more crop water use than either of the other two curves. Table 3 summarizes this information. The K_{cr} derived crop curve indicated 100 mm less water use than the crop curve in SCHED from planting to effective cover as well as for the season. It also indicated approximately 20 mm less crop water use when compared to Wright's curve. Differences between Wright's K_{cb} and the K_{cr}-based K_{cb} curve should be minimal since the K_{cr} is modeled after Wright's basal crop coefficient curve. Simulated irrigations using the K_{cb} curve from K_{cr} data lagged behind simulated irrigations using Wright's curve by 2 days during rapid vegetative growth; this was consistent with crop development as indicated by Fig. 2. With irrigations occurring two days earlier (Wright and K_{cr} comparison) than indicated by actual crop need during vegetative growth, potential exists for leaching nutrients out of the crop root zone.

The 1991 growing season basal crop coefficient curves are shown in Fig. 3. DOY 195 was used as the effective cover date for the SCHED and Wright K_{cb} curves which was based on LAI data. The K_{cb} curve derived from K_{cr} data did not peak until DOY 202. A hail storm

Table 4
Simulated irrigation dates and crop water use for the 1991 growing season

Basal crop coefficient curve					
SCHED		Wright		K_{cr}	
Irrigation date	Crop use (mm)	Irrigation date	Crop use (mm)	Irrigation date	Crop use (mm)
131	10.4	132	9.1	132	9.1
133	11.6	134	10.7	134	10.7
135	9.5	145	13.8	144	13.3
144	13.7	163	20.7	159	20.3
151	17.3	173	20.5	168	21.1
161	21.7	179	23.4	175	21.6
167	22.6	183	21.9	180	22.4
172	21.6	188	23.6	184	20.6
176	21.2	193	20.9	188	23.0
180	22.5	197	24.7	194	23.7
183	22.3	201	24.8	198	25.1
187	22.8	208	23.8	202	22.9
192	23.6	211	20.1	209	24.9
196	22.6	216	20.3	212	20.9
200	26.0	221	23.3	218	23.1
206	22.0	227	23.4	223	22.0
210	22.7	232	23.6	229	22.7
213	20.2	236	20.6	234	23.0
219	23.9	240	20.7	238	20.1
224	21.4	244	22.2	242	20.3
229	22.6	250	22.8	247	22.8
233	23.7			254	22.6
237	20.0				
243	24.2				
249	21.5				

Table 5
Simulated crop water use and number of irrigations for 1991 from planting to effective cover and for the growing season

Time period	Basal crop coefficient curve					
	SCHED		Wright		K_{cr}	
	Crop use (mm)	Irrigations	Crop use (mm)	Irrigations	Crop use (mm)	Irrigations
Effective cover	241	13	165	9	186	10
Dent	512	25	435	21	456	22

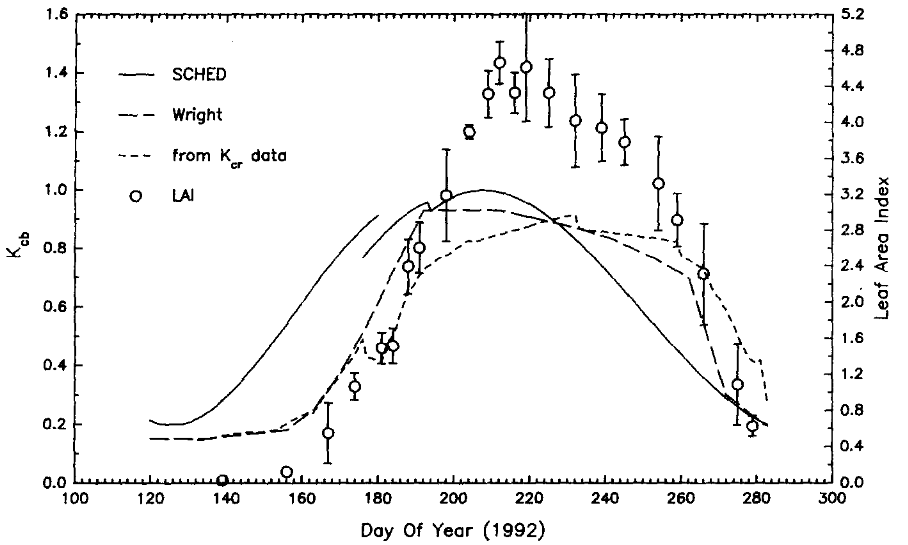

Fig. 4. Basal crop coefficient (K_{cb}) curves used in the 1992 growing season irrigation scheduling simulations.

occurred during the evening of DOY 220 which shredded the upper leaves. This event was detected by canopy reflectance data and the ensuing K_{cb} curve shows a definite decrease after DOY 220. As in 1990, simulated irrigation events and crop water use based on the K_{cb} in SCHED were greater than those estimated with the other two basal crop coefficient curves (Tables 4 and 5). Irrigations simulated with the K_{cr} crop coefficients occurred 3 to 5 days earlier than those simulated with Wright's crop curve during vegetative growth. This is in response to the crop developing faster early in the growing season than Wright's curve indicated (Fig. 3). Accumulated E_t between DOY 221 and 256 (day after hail damage and dent) for these two K_{cb} curves was approximately 10 mm less for the K_{cr} crop curve. Differences between these two basal crop coefficient curves were minimal again; the response was a function of actual growth conditions in the field.

Simulations for 1992 were conducted somewhat differently than those for 1990 and 1991. As mentioned in the methods section, irrigations were scheduled in 1992 using SCHED. Consequently, I retained the assumed effective cover date which was selected by a colleague; this date was chosen as 4 July (DOY 186). A guess at effective cover for Wright's basal crop curve was required also. Based on experience with this crop curve in this geographical setting, a simple empirical expression was developed to estimate the effective cover date which utilized a target planting date and the average number of days from planting to effective cover. Data from seven growing seasons were used. Simply stated, the assumed effective cover date is equal to the planting date plus 74 days minus half the difference between the planting date and the target planting date (25 April). Since planting occurred on DOY 120 (Table 1) and April 25, 1992 was DOY 116, the assumed effective cover date was calculated as DOY 192 (10 July).

Fig. 4 shows that Wright's K_{cb} curve and the K_{cb} curve from K_{cr} data agreed very closely until DOY 177. A severe hail storm occurred the afternoon of 24 June (DOY 176) which

Table 6
Simulated irrigation dates and crop water use for the 1992 growing season

Basal crop coefficient curve					
SCHED		Wright		K_{cr}	
Irrigation date	Crop use (mm)	Irrigation date	Crop use (mm)	Irrigation date	Crop use (mm)
127	9.7	130	9.2	130	9.2
132	10.9	132	9.7	132	9.7
140	15.0	155	20.1	155	20.4
152	21.0	166	20.1	166	20.3
158	20.7	171	20.1	172	21.5
164	21.9	179	21.6	181	21.8
168	23.0	185	23.3	187	21.9
172	22.5	190	22.1	192	22.7
180	21.1	194	22.1	197	21.4
185	24.9	199	22.9	203	22.0
190	23.1	204	22.4	208	22.0
194	22.7	209	24.2	212	21.6
199	23.4	213	21.6	217	22.3
204	23.7	218	22.0	222	22.7
209	25.9	223	21.9	228	23.6
213	23.0	228	20.4	233	20.2
218	23.3	234	22.6	241	24.6
223	22.8	241	21.6	247	23.6
228	20.1	247	22.9	252	20.7
234	21.8	253	23.3	257	20.9
242	22.5	259	22.6	262	20.5
249	22.4	266	22.4		
256	20.5				
265	20.7				

Table 7
Simulated crop water use and number of irrigations for 1992 from planting to effective cover and for the growing season

	Basal crop coefficient curve					
	SCHED		Wright		K_{cr}	
Time period	Crop use (mm)	Irrigations	Crop use (mm)	Irrigations	Crop use (mm)	Irrigations
Effective cover	237	12	168	9	148	8
Dent	507	24	459	22	434	21

left very tattered corn plants. Corn growth on this day was designated as V7. The K_{cb} curve derived from K_{cr} data had the capability of tracking this event. The planting and assumed effective cover dates in SCHED were shifted forward one week to compensate for delayed corn growth; thus, the revised effective cover date was 11 July (DOY 193). This was done to mimic use of the crop coefficient curve in SCHED for the simulation as it was used in the 1992 growing season. No attempt was made to revise Wright's K_{cb} curve. Based on measured LAI data which is somewhat questionable due to shredded leaves in the lower portion of the canopy (V10 and below), the best fit curve through the data indicated that LAI = 3 on DOY 195. The K_{cb} curve derived from K_{cr} data did not peak until DOY 232 which was well after tasselling. This occurred because there was insufficient biomass in the crop canopy to shade the soil between corn rows which indicates that reflectance data may be more closely associated with shading of the ground by the crop canopy than with LAI of the crop canopy.

As in 1990 and 1991, simulated irrigation events and crop water use for 1992 were greater using the K_{cb} in SCHED (Tables 6 and 7). Crop water use was approximately 90 mm greater than that simulated using the K_{cb} from K_{cr} data for the time period planting to effective cover. The difference in crop water use between Wright's K_{cb} and the K_{cb} derived from K_{cr} data was again around 20 mm; this time it was less for the reflectance-based crop curve. After the hail storm, irrigations simulated using the K_{cb} from K_{cr} lagged irrigations based on Wright's K_{cb} by two to three days prior to effective cover in response to actual crop development in the field.

4. Conclusions

A procedure was developed to estimate a daily basal crop coefficient (K_{cb}) from linear curve segments defined by the reflectance-based crop coefficient (K_{cr}) calculated from canopy reflectance data. Fraction of accumulated growing degree days from planting was used as the independent variable. Ideally, canopy reflectance data used to calculate the K_{cr} should be acquired when clouds do not obscure the sun. K_{cr} data should be available at least weekly to adequately estimate the K_{cb} with this procedure.

Crop water use and irrigation events were simulated for center pivot-irrigated corn during three growing seasons using SCHED (USDA-ARS Irrigation Scheduling Program). The K_{cr}-based K_{cb} curve was compared to the K_{cb} curves defined in SCHED and from tabulated data by Wright (1982). Differences in estimated crop water use and number of irrigations using the K_{cb} curve in SCHED compared to the K_{cb} curve derived from canopy reflectance data ranged from 60 to 100 mm more and three to six additional irrigations, respectively, for the SCHED K_{cb}. Averaged simulated results for the three growing seasons indicated that the number of irrigations were reduced by 15.6% using the K_{cr}-based K_{cb} as opposed to the K_{cb} in SCHED; estimated crop water use was reduced by 14.5%. Comparisons with Wright's K_{cb} curve were less dramatic. Estimated water use was approximately 20 mm less in 1990 and 1992 and 20 mm more in 1991 for the K_{cr}-based K_{cb} curve; number of irrigations was one less in 1990 and 1992 and one more in 1992. These small differences were expected since the K_{cr} was modeled after Wright's curve. However, irrigation events often occurred

3 to 5 days earlier or were delayed two to three days for the K_{cr}-based K_{cb} curve as opposed to Wright's K_{cb} curve; this was in response to crop development.

The basal crop coefficient curve derived from the reflectance-based crop coefficient for corn was unique for each growing season. It does not require an estimation of effective cover. Furthermore, it is a direct representation of actual crop growth conditions in the field. Consequently, irrigation scheduling for corn could be improved by using canopy reflectance data to determine crop coefficients. Overirrigation as well as underirrigation are minimized due to better estimates of crop water use and appropriate timing of the irrigations.

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